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REFLECTION FROM HOLLOW ARMOUR UNITS

by

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ABSTRACT

Model investigations are carried out in using irregular and monochromatic waves synchronously acting on 2 sloping structures $1:n = 1:2$ in order to demonstrate the advantages of a new designed structure composed from hollow armour units ("Hollow Cubes") versus a conventional smooth sloping structure. The energy of the water level deflections in front of the hollow armour units piled up to form a stepped-face hollow seawall structure appears to be reduced by about -65% with reference to a smooth structure. Reflection coefficients found for the new design are appreciably less than those found previously for 1-layer hollow revetment elements on a slope $1:n = 1:3$, - particularly at the longer waves. The efficiency of such a structure can be explained (1) by the existence of the cavities in the armour blocks affecting the washing movement, (2) by causing energy losses at the inflow and outflow from the structure and (3) by wave splashing at the stepped structure.

1. INTRODUCTION

There are several phenomena known to be responsible for failures of revetment or seawall structures respectively: periodically differing pressure fields on both sides of revetment elements, impact forces due to breaking waves, wave run-up and overtopping, up- and downrush velocities etc., all of them being dominated by the breaker height.

With respect to the transfer mechanisms of wave induced loadings on such sloping structures the author in 1991 [1], [2] first pointed out the phenomenon consisting in

the interaction processes between the washing movement on the slope face and the wave induced particle movement in front of the sloping structure due to reflection.

Making the assumption that the movement of the mass of water in front of a sloping structure can be regarded as an oscillating continuum (characterised by different natural frequencies according to the actual geometric boundaries), the source of excitation can be realised in the waves coming from sea, and the different degrees of freedom are represented - on the one hand - by the deflections associated with a set of individual partial standing waves (partial clapotis) (Büsching, 1992)[3] and - on the other hand - by the washing movement due to run-up and run-down of broken waves on the slope face. Because in such an arrangement (coupled oscillating system) the influence on one degree of freedom has an effect on the remaining degrees of freedom, the author proposed to separate the washing movement from the remaining flow field in order to avoid interaction processes between them [1]. As a matter of principle this can be achieved by double sheathing structures, consisting of an inner and an outside coverlayer with a cavity between them.

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Such structures composed of hollow concrete elements can preferably be used for revetment structures. Several shapes have been tested in a model scale and a prototype structure exists at the harbour entrance of Baltrum Island/North Sea [3],[5]

In the case of rubble-mound-breakwaters or similar seawall structures bigger size hollow armour units can be designed, simultaneously forming the basic supporting system.

A large variety of proposals is contained in the respective patent documents (Büsching, 1991)[2].

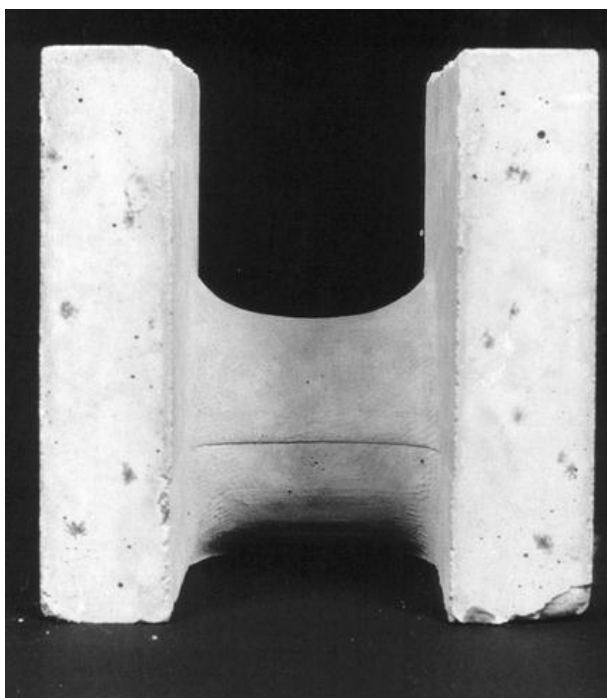
2. MODEL INVESTIGATIONS

Model investigations of scale 1:5 and slopes $1:0 \geq 1:n \geq 1:3$ have been executed in the Hydraulic Laboratory of Bielefeld University of Applied Sciences since 1990. First results on irregular water level deflections synchronously measured in front of a smooth and a hollow sloping structures 1:3 had been published previously by the author in 1992 [3]. The most important outcome from that work consisted in the finding that reflection from a sloping structure - whether smooth or hollow - strongly depends on the frequencies contained in the spectrum of gravity waves. The lower the frequency components the more downslope they are reflected. Due to such a response from the sloping structure a set of partial clapotis could be detected to be present coincidentally in front of the sloping structure. The partial clapotis - each composed from a number of bound frequency components of the same wave length and by this reason possessing of an anomalous dispersion - being the more pronounced (by bigger reflection coefficient) the lower its mean frequency.

In 1995[5] the author concentrated measurements on the *very vicinity* of the slope 1:3 including the breakers. Because wave gauges could not be used at that water depth, pressure devices, spaced less than 10cm, had been placed on the slope face. Applying synchronous spectrum analysis on the pressure signals in a similar way as before on the wave gauge signals, the coincident presence of partial standing waves could even be confirmed *in the breaker zone*.

Moreover different shapes of “pressure energy distributions” on the smooth and on the hollow slope faces could be attributed to plunging and collapsing breakers respectively.

2.1 Test Structure



The model tests, the present work is based on, refers to a steeper slope (of a seawall) $1:n = 1:2$ protected by so-called “Hollow Cubes”.

Such a kind of cubes (scale 1:5) made from concrete is formed by two lateral walls with a stem between them. In this case the stem is placed at one edge of the cube and the lateral length of all cube sides is 0.2m, see Fig.01. The cavity reduces the mass of the cube by more than one third.

The particular shape of the cube had previously been designed in order to place hollow cubes in one layer parallel to a prefabricated smooth slope, see Fig.02. In the present investigation, however, two layers of cubes are piled up in such a way that a stepped structure is formed, see Figures 03 to 05.

Fig. 01: Hollow Cube consisting of two lateral walls and a stem at one bottom edge of the cube.

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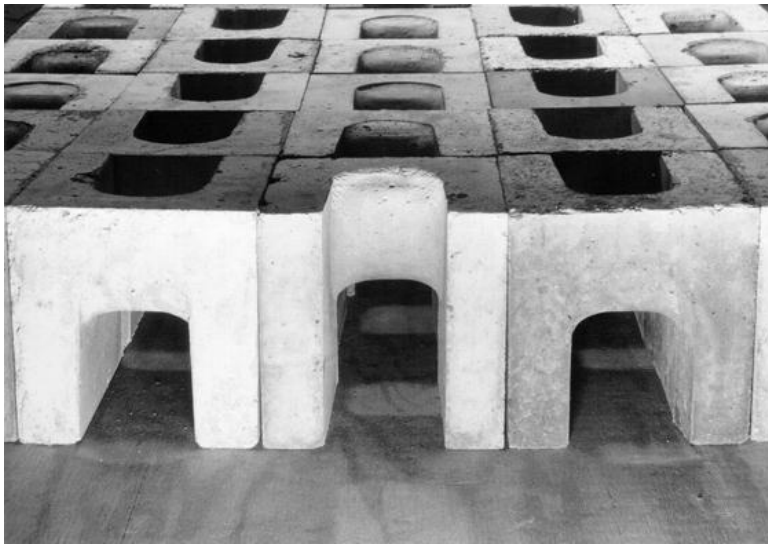


Fig.02: One Layer of Hollow Cubes Placed on a Smooth Slope. (Stems at upper edges)

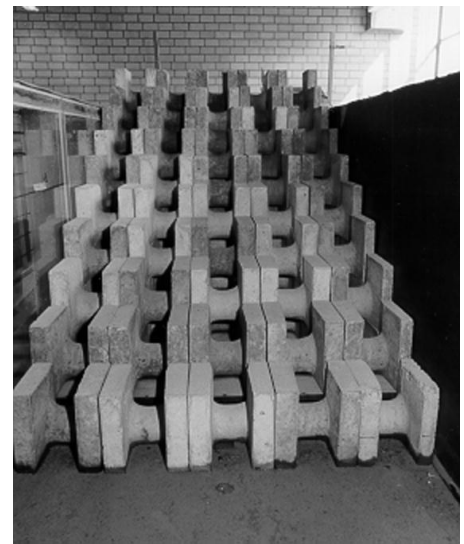


Fig.03: Two layers of Hollow Cubes forming a stepped structure

2.2 Model Setup

The particular model arrangement is still oriented at the prototype conditions corresponding to the harbour entrance of Baltrum Island/North Sea. Here an 8 m high breakwater was built in 1992 in a water depth of about 4.5 m (MHW).

Moreover the measuring procedures and the signal processing applied are similar to those used for the previous investigations, see [3],[5]. Because of the water depth conditions to be considered in the model, the input wave spectrum used was similar to those measured near the breaker zone of Sylt Island/North Sea (Büsching, 1976)[7]. Hence, in the model input and response spectra (scale 1:5) the energy densities are concentrated around a median frequencies $f = 0.56$ Hz corresponding to a wave group short enough to not be rereflected from the wavemaker. Although the shape of the input spectrum used for some previous investigations was different, it will be shown that the respective results can nevertheless be compared to the results already available from the previous investigations as well as to the actual results of the set of monochromatic waves comprising frequencies $0.36 \leq f \leq 0.70$ Hz and wave steepnesses $1:100 \leq H/L \leq 1:25$, see further below.

With respect to the requested evaluation of reflection coefficients it was necessary to extend measurements of water level deflections on a distance of at least one third of the longest wave length investigated. Hence, at some 30 wave gauge stations (equally spaced 10 cm) synchronous measurements were performed both in front of the hollow and the smooth slope. Because of the special stuctur of the hollow elements it was possible to place the first wave gauge (number 0) very close to the point of intersection of the SWL with the slope face, see Fig. 04. On the smooth slope, however, at the corresponding position the water depth was to small for the operation of a wave probe. That is why referential measurements for both slopes are available for stations 1 through 31 only. The signals from the wave gauges were measured synchronously and in this case were processed by spectrum analyses confined to a total frequency ranges of 0 to 5 Hz. The changes in the response spectra with the distance from the hollow and the smooth sloping structures are demonstrated by Fig. 06 and Fig. 07 respectively.

In these figures the upper curves plotted along with the probe station numbers represent the total energy contents of the response spectra. Those values are found by integrating the total spectra.

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Moreover the energy contents of 11 adjacent frequency ranges (as specified in the graphs) are shown by the separating curves below.

The measurements as well as data analyses had been carried out by Lemke and Nicolai (1998) [8].

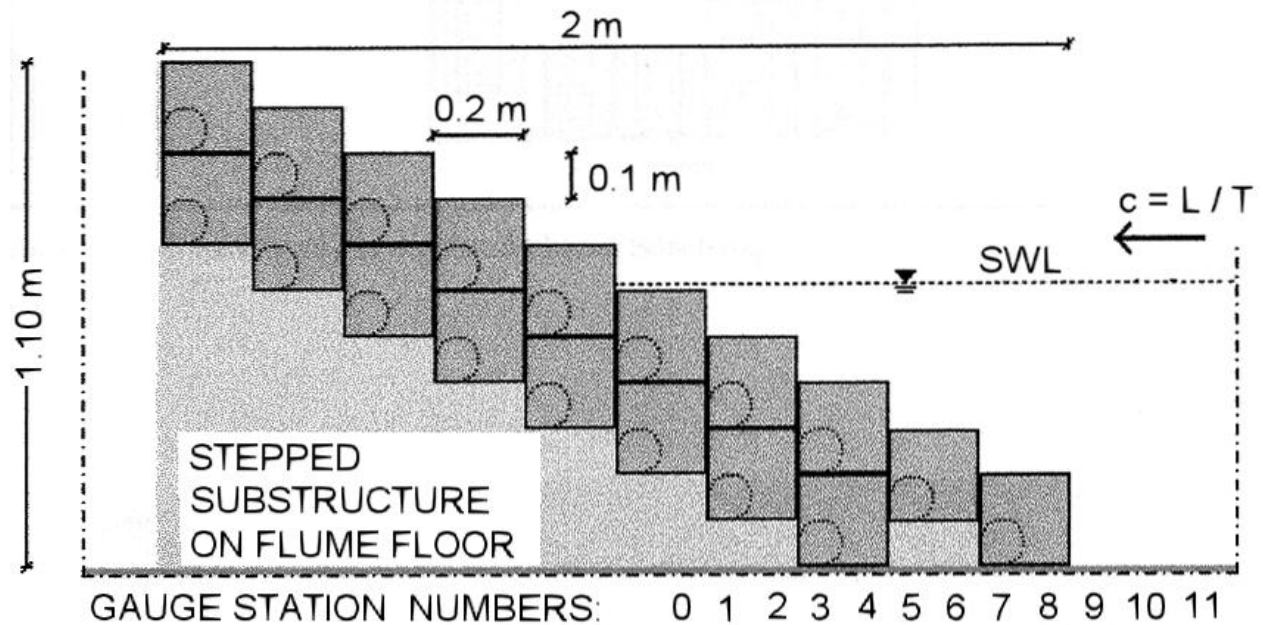


Fig. 04: Sectional View of the Test Structure Composed of "Hollow Cubes"

Two Layers on a Stepped Substructure.

Positioning of Wave Gauges in the vicinity of the Test Structure at Flume Center Line.

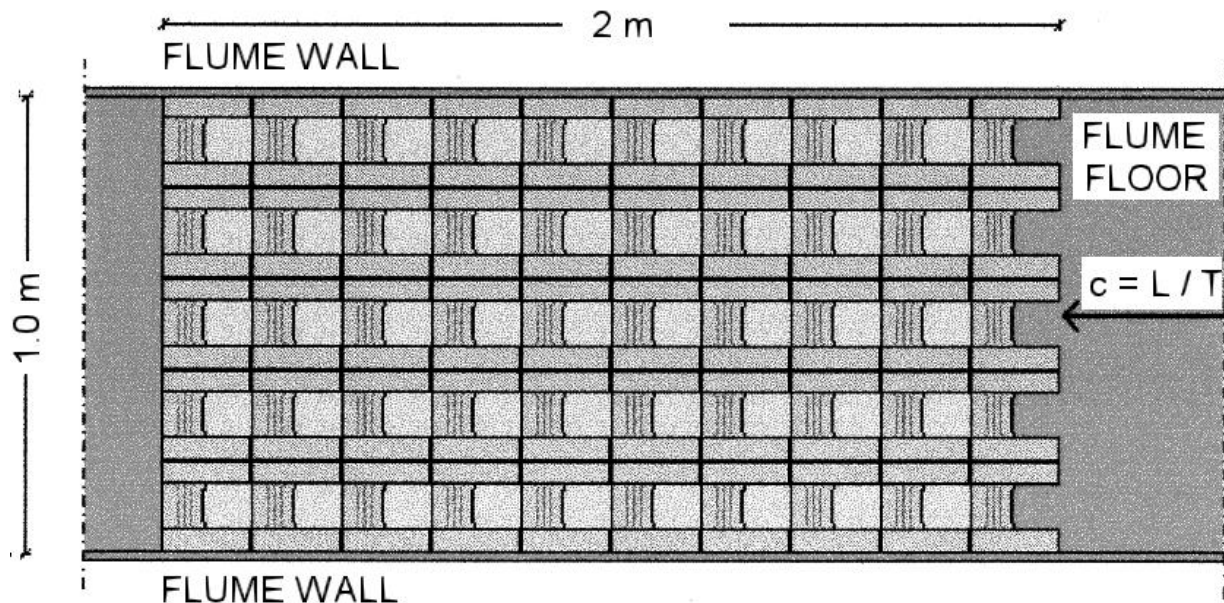


Fig.05: Plan View of the Test Structure

Especially from Fig. 06 it can be seen clearly that – except for the first and the last frequency range - the areas between the curves dispose of nodes and antinodes characterizing the phases of minimum and maximum partial clapotis energy respectively. Hence, reflection coefficients $C_{R,i}$ belonging to those confined frequency ranges of the response spectra in this case can be approximated in applying

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$$C_{R,i} = \frac{\sqrt{E_{\max,i}} - \sqrt{E_{\min,i}}}{\sqrt{E_{\max,i}} + \sqrt{E_{\min,i}}} \quad \text{Where :}$$

E_{\max} = maximum energy of contributing components at clapotis antinode,

E_{\min} = minimum energy of contributing components at clapotis node,

i = number of clapotis.

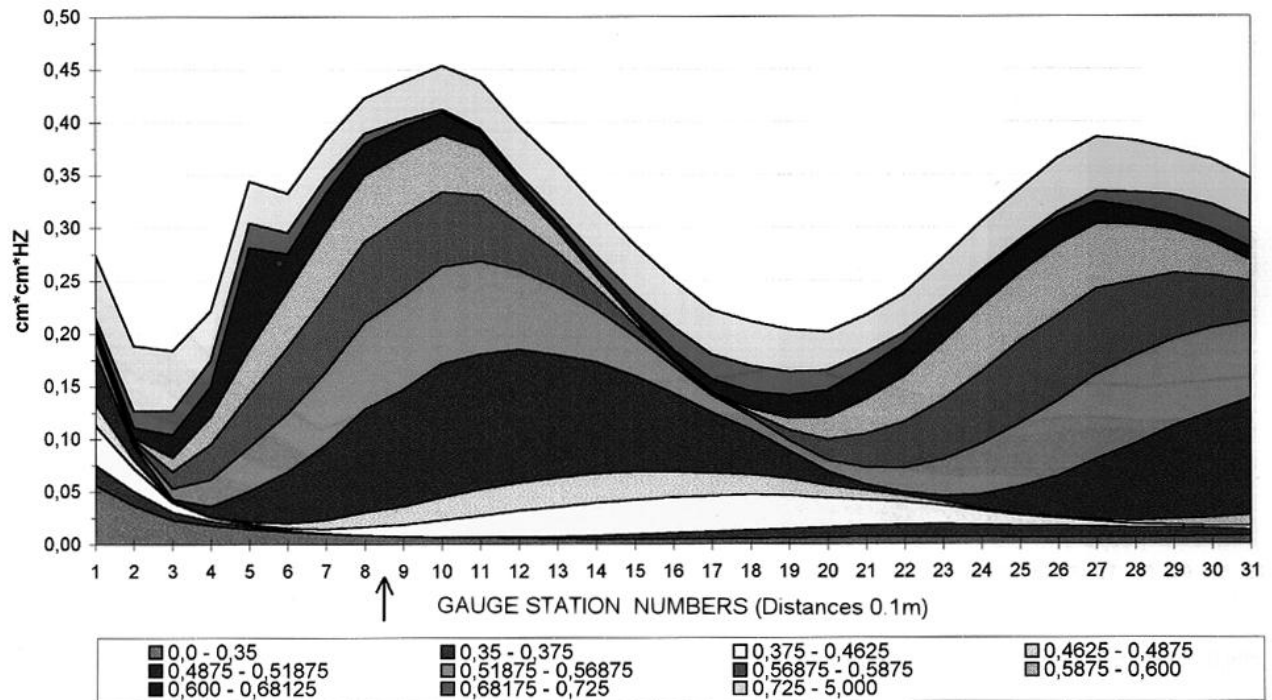


Fig.06: Upper Curve: Total Spectrum Energy with Distance from the Smooth Slope.

Curves below: Define the Energy Content of the Frequency Bands Indicated.

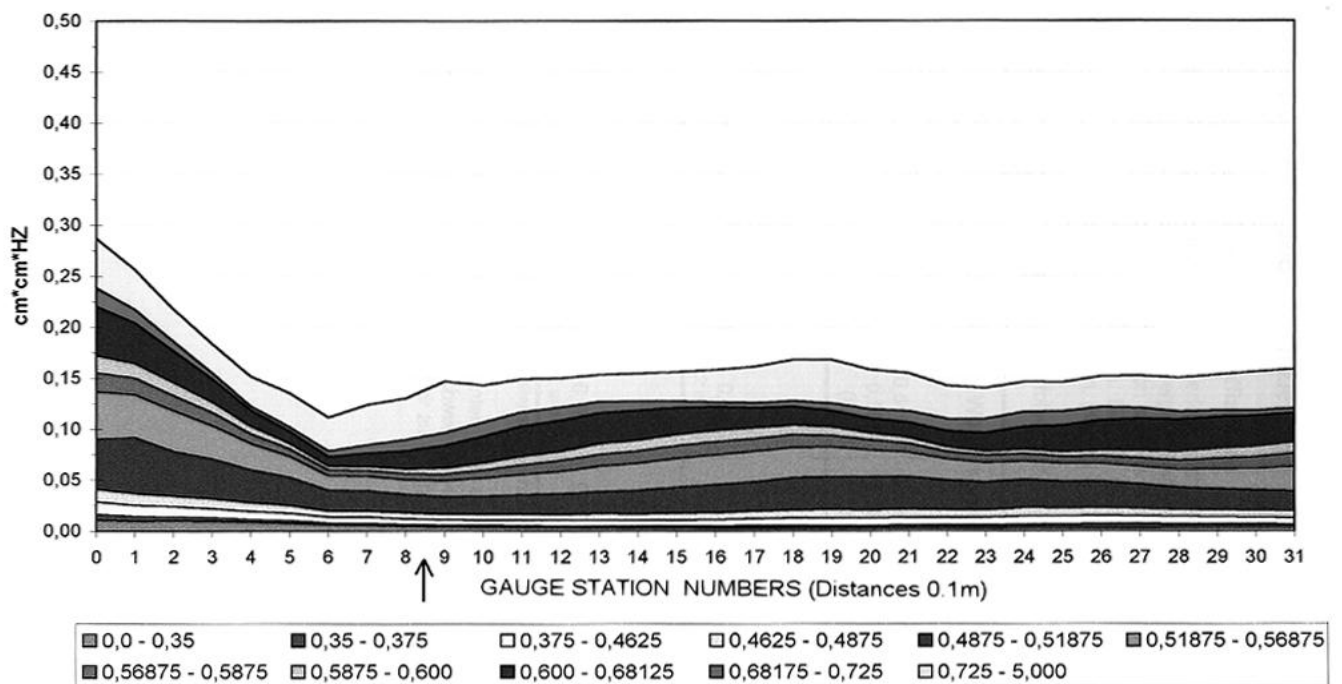


Fig.07: Upper Curve: Total Spectrum Energy with Distance from the Hollow Slope.

Curves below: Define the Energy Content of the Frequency Bands Indicated.

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A similar procedure was adopted to evaluate reflection coefficients for the set of monochromatic waves with frequencies $f = 0.36; 0.47; 0.5; 0.53; 0.59$ and 0.7 Hz, which were analyzed additionally.

3. RESULTS

Discussing the results contained in Figures 06 and 07 at first the following restrictions can be made:

1. The signal variances in the highest frequency ranges $0.725 < f < 5\text{Hz}$ (upper most areas), almost being constant at any measuring station, apparently are due to signal noise and therefore should be ignored.
2. At station number 5 on the smooth slope (Fig.06) there was an additional peak in the frequency range $0.6 < f < 0.68125$ Hz apparently due to some unknown signal disturbance.
3. The lowest frequency range ($0 < f < 0,35\text{Hz}$) of the spectrum can at least partly be excluded from the discussion, because the accuracy of spectrum analysis is low at those frequencies.

In order to attach the curves in Fig.06 and Fig.07 to the two sloping structures, the position of the structure foot is assigned by vertical arrows between measuring stations 8 and 9.

Hence, it can be seen from Fig.06 that maximum spectrum energy (proportional to the square of vertical displacement of water particles) exists at station number 10, which is still in front of the foot of the smooth slope, whereas the minimum energy is located on the structure between station numbers 2 and 3. Further away from the slope face the total energy content oscillates almost periodically with the distance from the slope. It can be presumed that this feature is continued in the seaward direction with the amplitude decreasing. This energy distribution can be looked upon as to be due to a resultant partial clapotis, which is composed from a set of partial standing waves formed by some frequency components.

With regard to the phase relationship of nodes and antinodes of those partial clapotis formed by the denoted confined frequency ranges, it can be seen clearly that the respective distances from the line of intersection of the Stillwater level with the slope face are larger the longer (lower) the attributing frequencies are. Because of the distinct nodes (and antinodes) especially at the longer frequencies, it can be stated that at the smooth slope 1:2 reflection is most intense at the longer frequencies.

As expected the distribution of energy in front of the hollow structure (Fig.07) differs very much from that on Fig.06. Here there is the recorded maximum of energy at station number 0, which is very close to the point of intersection of the SWL with the slope structure. The minimum of the total energy is at station number 6, which is considerably further away from the sloping structure than it is at the smooth slope (station number 2 and 3). The overall impression with respect to the distribution of the total energy in front of the structure is, that it is far away from being periodic.

A weak periodic nature can, however, be attributed to the curves separating the selected confined frequency ranges. Hence, it was possible to extract reflection coefficients C_R (as described above) from both Figures 06 and 07, see Fig.08.

In correspondence with the energy minimum at station number 6 a striking feature in Fig.07 consists in the fact that there is a tendency for all partial clapotis to have a node near to station number 6. This means that the respective antinodes also are located at positions further away from the hollow structure.

Comparing the distributions of the energy present in the washing movement on the smooth slope (at station number 1) to that on the hollow slope (at station numbers 0 and 1) the total amounts of energy do not differ very much. But there is a remarkable difference in the distribution of the energy on the adjacent frequency ranges: Taking the smooth slope as a reference, energy has "shifted" from

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lower frequencies ($0 < f < 0.46875\text{Hz}$) to higher frequencies ($0.4875 < f < 0,725\text{Hz}$) on the hollow slope. Referring to visual observation this is in accordance with more intense breaking action on the hollow slope than on the smooth slope.

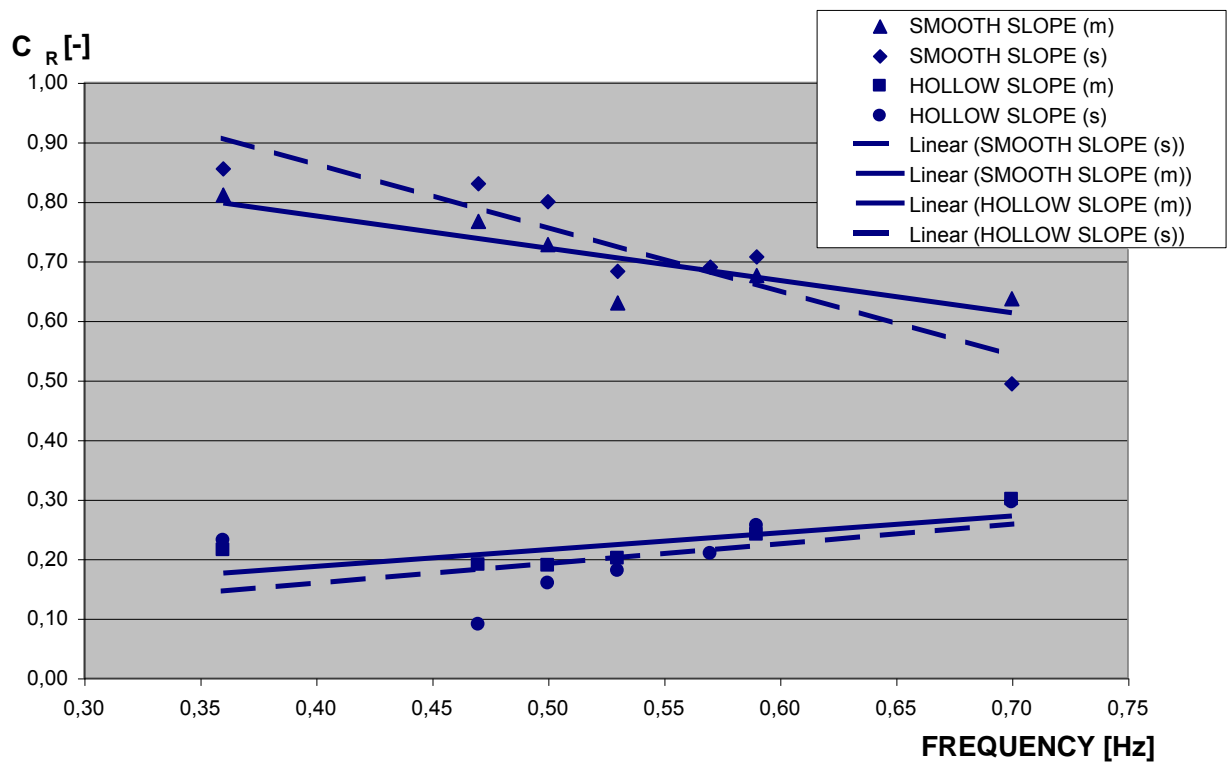


Fig.08: Reflection Coefficients on the Hollow Slope versus the Smooth Slope.
(m) = data from monochromatic waves; (s) = data from wave spectra.

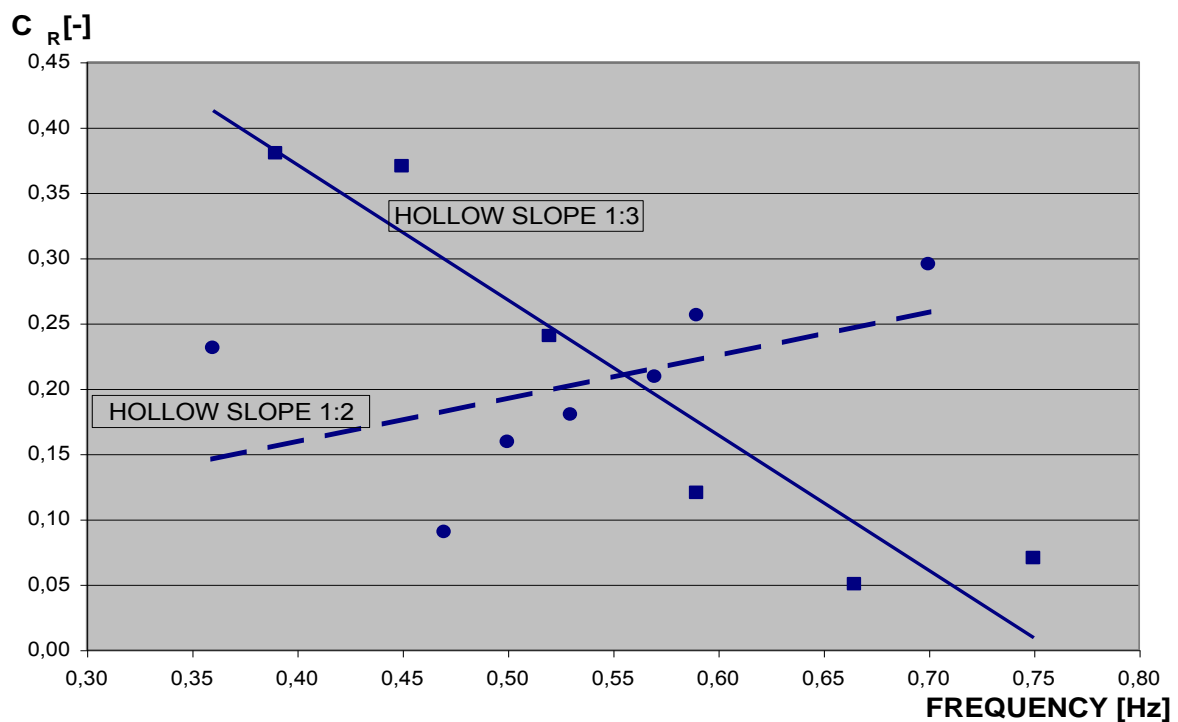


Fig.09: Reflection Coefficients on the Hollow Slopes 1:2 versus Hollow Slope 1:3.

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4. CONCLUSIONS

Apart from the wave induced forces on sloping structures the influence of water level deflections is important with respect to the maneuverability of a ship in the vicinity of a sloping structure.

The proposed type of hollow structure, if compared to a smooth slope, in the present case is capable to reduce the energy contained in the water level deflections in front of the structure by about -70% (at station 10) or -65% (at station 27), see Fig.06 and Fig.07.

Hence, qualitatively the overall results of the present work on slopes 1:2 are on a level with the previous work mentioned above.

Taking previous results on a slope 1:3 [3] (constructed in using 1 layer of hollow revetment elements) as a reference to the actual findings at a slope 1:2 (consisting of piled up hollow armour units), however, the following discrepancies are found:

1. The maximum reduction of energy at the less inclined hollow slope 1:3 is -40% only.
2. The change of reflection coefficients with frequencies is different on the two hollow slopes, see Fig. 09.

Reflection coefficients on the slope 1:2 are smaller at lower frequencies and bigger at higher frequencies. The respective trend lines are opposite, however, for frequencies higher than $f = 0.47\text{Hz}$ only. Hence, from the above statements there is an indication that the better efficiency of the piled up structure (1:2) is predominantly due to the lower frequency components of the spectra.

An explanation can be deduced from some visual observations: In deed, there is a big difference in the movements of water particles on the two structures. At the one-layer structure (1:3) the influence on the interaction of the washing movement with the reflection induced flow field is dominating, whereas at the piled up stepped structure some additional breaking (splashing) occurs together with energy losses at the inflow and outflow from the structure.

Last but not least there is an indication that the efficiency of any hollow structure can be improved by selecting a smaller ratio of the wave height divided by lateral cube length.

6. REFERENCES

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